ZTE Imaging with T1 Contrast

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Introduction Techniques with zero or near-zero echo time like ZTE[1-5], SWIFT[6], or PETRA[7] enable efficient direct MRI of tissues with very rapid transverse relaxation. The absence of gradient switching during signal encoding with high bandwidth provides high robustness against eddy current and off-resonance effects. In addition, ordering the directions of 3D radially applied gradients in a smooth manner reduces acoustic noise of such sequences close to ambient level[8]. The approaches differ mainly in how broadband excitation is achieved and in their way of obtaining data in the k-space centre. SWIFT relies on extended frequency-swept excitation and interleaved transmit-receive (T/R) operation, while the PETRA technique involves additional finite-TE acquisitions to fill the k-space centre. ZTE addresses both of these issues with particularly rapid T/R switching after hard-pulse excitation, which maximizes the net acquisition time and permits algebraic reconstruction of the k-space centre without additional acquisition. Using repetition times in the sub-millisecond range[8] the ZTE variant is also very fast and thus attractive beyond short-T2 applications. However, so far it has not been leveraged for other contrasts, which are not straightforward to achieve at zero TE and small flip angles. To expand the contrast versatility of ZTE imaging, this work explores the utility of magnetisation preparation and presents a first implementation of ZTE imaging with T1 contrast.

Methods ZTE imaging employs 3D radial centre-out encoding where zero TE is achieved by setting the readout gradient *before* excitation with a short hard-pulse. Switching from RF transmit to receive operation creates an initial dead time which makes ZTE data incomplete in the k-space centre. The latter is addressed by radial acquisition oversampling and finite support extrapolation[5,10,11] but nevertheless must be kept small[12,13]. Experiments were performed on a 7 T human whole-body MRI scanner (Philips Achieva) complemented with custom-built RF transmit and receive systems[8]. The latter enabled a short initial dead time of only 5 µs by employing high-power RF transmit pulses of 3 µs length, rapid transmit-receive switching within 1 µs and digital filtering with group delay 2.6 µs. A quadrature volume head coil (Nova Medical) was used for both RF transmission and reception. ZTE imaging was performed with a matrix size of 256 in a field-of-view (FOV) of 530 mm, resulting in an isotropic spatial resolution of 2.07 mm, where the large FOV was necessary to avoid aliasing of signal from the RF coil (Fig. 2). A bandwidth of 250 kHz was used with four-fold oversampling. The acquisition of 321600 radial spokes with a TR of 736 µs and flip angle ≈ 2° resulted in a scan time of 4 min for the non-prepared ZTE scan. Applying the gradients in a continuous manner allowed virtually silent gradient operation[8]. For creating T1 contrast, similar to gradient echo-based MP-RAGE[14], an adiabatic inversion pulse (HS1, 1 kHz, 2000°) was applied, followed by a delay of 700 ms, an interval of 1000 ms with a series of ZTE acquisitions, and a recovery time of 1300 ms (Fig. 1). Thus, the scan time was prolonged to 12 min while acoustic noise was negligibly increased due to clicking during the on- and offset of the ZTE gradient. After 1D algebraic reconstruction, 3D gridding was used to generate the 3D data sets. Bias correction for B1 non-uniformity was accomplished with the FSL FAST software[15], and reformatting and interpolation was performed with "3D Slicer".

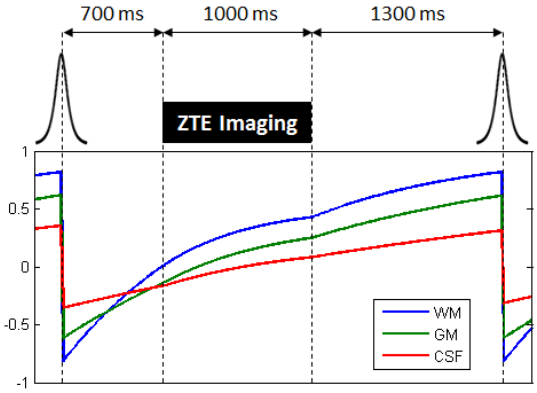

Figure 1 Scheme for magnetisation-prepared ZTE imaging with T1-weighting. The simulated signal course is depicted for white matter (WM, T1 = 1126 ms), grey matter (GM, T1 = 1939 ms), and cerebrospinal fluid (CSF, T1 = 4470 ms).

Results ZTE brain imaging was performed in healthy volunteers. Figure 2 displays an axial slice of a head exhibiting B1 non-uniformity typical at 7T as well as short-lived signal from the RF coil and the head set. Figure 3 shows three orthogonal views of the 3D data sets at isotropic spatial resolution. The bias-corrected images exhibit excellent uniformity and good SNR. Without preparation, larger signal is observed for grey than for white matter, associated with higher water proton-density. The preparation results in a typical T1 contrast with suppressed CSF and larger relative signal for white matter. Furthermore, fat in the scalp appears bright due to short T1 and also the relative signal level of the skull is increased. Despite the generally reduced signal (Fig. 1), the SNR is still sufficient.

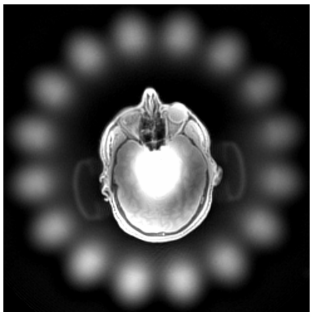

Figure 2 ZTE image showing short-lived signal from the RF coil and B1 non-uniformity as typical at 7T.

Discussion ZTE imaging with T1 contrast was demonstrated in the human brain. When targeting direct MRI of tissues with very short T2, the presented approach has the potential to separate them from long-T2 species based on differing T1. Moreover, the beneficial features of this efficient, robust, and silent technique are also of interest beyond the typical short-T2 applications. A similar approach had been demonstrated previously for the related methods SWIFT[16] and PETRA[17]. In the latter, a relatively large gap in central k-space is filled with data obtained with single-point acquisition. By means of an optimised ordering these are utilised to emphasise the magnetisation-prepared contrast. As could be shown in the present work, comparable results can be obtained for pure ZTE without these measures. Several routes are available for further enhancing the performance of the technique. Using RF coils with negligible proton background signal will enable a strongly reduced FOV. Hence, the scans shown here will be possible within only about 1 and 3 min, respectively. Higher SNR will be available by using separate receive arrays which offer higher sensitivity than the RF coil used in this work, thus also enabling higher spatial resolution. Moreover, the timing scheme employed (Fig. 1) could be further optimised for larger signal levels and possibly shorter scan time. If required, the added clicking sounds can be eliminated without compromise by ramping up / down the first / last gradient with reduced slew rate. Contrast in ZTE images can be further modified by other magnetisation-preparation techniques using the same approach.

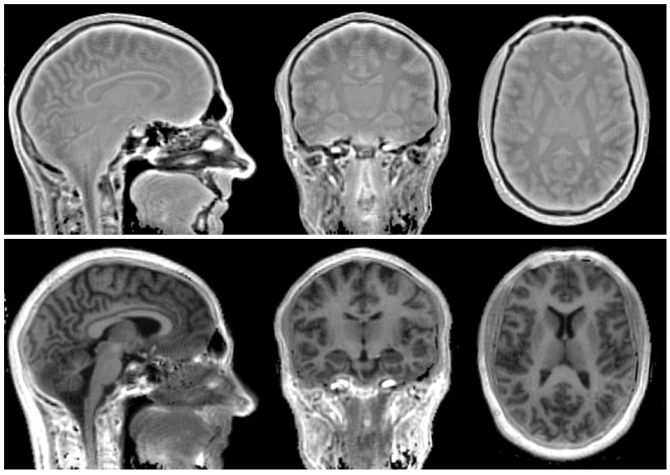

Figure 3 ZTE imaging of a human brain without (top) and with (bottom) magnetisation-preparation according to Fig. 1.

References 1. Hafner S, MRI 12 (1994) 1047. 2. Madio DP, MRM 34 (1995) 525. 3. Kuethe DO, MRM 39 (1998) 85. 4. Wu Y, Calcif Tissue Int 62 (1998) 512. 5. Weiger M, eMagRes 1 (2012) 311. 6. Idiyatullin D, JMR 193 (2008) 267. 7. Grodzki DM, MRM 67 (2012) 510. 8. Weiger M, MRM 79 (2013) 328. 9. Weiger M, MRM 66 (2011) 379. 10. Jackson J, MRM 11 (1989) 248. 11. Kuethe DO, JMR 139 (1999) 18. 12. Weiger M, ISMRM (2011) 747. 13. Weiger M, ISMRM (2013) 2632. 14. Mugler JP, MRM 15 (1990) 152. 15. Zang Y, IEEE TMI 20 (2001) 45. 16. Corum CA, ISMRM (2009) 2772. 17. Grodzki DM, ISMRM (2013) 456.